

# **Modeling the Santa Barbara Channel Using Realistic Open Boundary Conditions and Winds**

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## **LONG-TERM GOAL**

To numerically model basic small-scale coastal phenomena using ultra-high resolution on advanced computers for ultimate development of a nowcast/forecast system.

## **OBJECTIVES**

The main objective is realistic modeling of the Santa Barbara Channel (SBC) leading to nowcast/forecast capability. This goal requires accurate winds and open boundary conditions, and a model having adequate representation of the surface mixed layer dynamics; good accuracy for the dominant Coriolis and internal wave propagation terms; realistically small numerical dissipation and dispersion; and a good representation of the bottom boundary layer especially in shallow coastal regions.

## **APPROACH**

To achieve the above goals, the basic approach used was nesting of the high resolution (one minute) DieCAST SBC model within the DieCAST California Current (CC) model in collaboration with the Naval Postgraduate School (NPS). The emphasis was to use realistic wind forcing with an existing mixing approach, and to implement a good nesting approach which provides good open boundary conditions for a high-resolution SBC model. A key contributor to this effort was Dr. Avichal Mehra, who assisted in conducting many of the model runs.

## **WORK COMPLETED**

A modified Arakawa "a" grid SBC version of DieCAST was nested within the CC model developed in collaboration with NPS (Drs. Bob Haney and Bob Hale). Even with no sponge layers, the open SBC boundaries had little noise. The nested SBC results (1/60 degree resolution) were consistent with the lower resolution (1/12 degree) CC model results in the same region, yet rich in internal smaller-scale features that were not resolved by the coarser CC model.

Observed coastal mesoscale (40 km wide, 3-10 dynes/cm-cm) wind forcing jets were added to the CC model. These elongated jets stretched southward from main coastal headlands. Their monthly mean surface stress was ~3 dynes/cm-cm along the jet centerline. Synoptic events often give  $O(10)$  dynes/cm-cm.

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Results using Hellerman summer winds, enhanced by the 3 dyne/cm-cm summer mean forcing, showed significant differences compared to results using only Hellerman winds. Thus, it may be necessary for coastal models to respond accurately to such small (40 km) scale wind jets to get realistic near-shore flow results. DieCAST responded strongly using 1/12 deg resolution.

The SBC had near zero mean through flow, because of a near balance between a local-wind-forced surface Ekman layer flow and its associated upwelling (northern SBC) and downwelling (southern SBC) distribution, and external effects from the Davidson Current and the CC system. Fluctuations away from this near balance led to the four main SBC regimes.

## RESULTS

Based on a series of sensitivity studies with our 1/60 deg resolution SBC model nested in our 1/12 deg resolution CC model, culminated by those reported by Dietrich and Mehra (1998), we have achieved a good understanding of the SBC general circulation dynamics. The SBC general circulation is primarily an Ekman layer response to local wind forcing modified by stratification, dissipation and mixing along its perimeter, and open boundary effects from the CC.

We also have demonstrated (Dietrich and Mehra, 1998) that our SBC model nested in our CC model gives realistic mean flow as well as the main observed flow regimes reported by Harms (1996). This includes details such as a stronger eastern port time mean inflow at 50 m depth than at the surface. The main findings from this research, supported by results shown by Dietrich and Mehra (1998), include:

- Given realistic climatological wind forcing with the annual cycle specified only in the mountain shadow winds (no mountain shadow during winter), the DieCAST model gives surface and 50 m depth mean flows (Dietrich and Mehra, 1998) that are strikingly similar to observations reported by Harms (1996).
- Local wind forcing is a critical issue. A very narrow (~8 km) mountain shadow along the north rim of the SBC, together with wind turning into the channel along the south rim, as observed, is required to get realistic mean climatological westward north rim and eastward south rim flows in the SBC central basin, and the main observed fluctuations from the mean.
- The local wind forcing effects are primarily through its associated surface Ekman layer drift and upwelling distribution, rather than direct vorticity generation by wind curl.
- The upwelled CC coastal jet water tends to separate near Point Conception, and entrain some of the flow from the east along the north rim of the SBC (the rest recirculates within the SBC). It thus has substantial effects on the SBC circulation, as we correctly hypothesized earlier.
- The mean latitudinal averaged flow through the SBC is small, but oscillates. This, together with peripheral small-scale mixing eddies around the SBC rim, suggests that dissipation may play a major role in the maintenance of the dominant central cyclonic vortex, based on simple absolute potential vorticity dynamics mechanisms. This is discussed by Dietrich and Mehra (1998). Similar mechanisms were previously discussed by Bretherton and Haidvogel (1976); Salmon, Holloway and Hendershott (1976); and Carnevale and Frederiksen (1987). This mechanism tends to maintain cyclonic flows over deep central basins of semi-enclosed seas, including the Adriatic Sea and Black Sea, as well as the SBC.

We thus expect that, given accurate synoptic winds and open boundary conditions, the DieCAST model will give accurate nowcast/forecast results. Hindcast synoptic wind inputs are presently being prepared by our collaborators at NPS, in order to have a consistent basis for comparison of the DieCAST and Princeton Ocean Models. Such a comparison will lead to better understanding about coastal modeling capabilities in general (DieCAST and Princeton are quite different, so good information should result) as well as the relative strengths and weaknesses of the individual models.

In summary, surface Ekman layer flows and associated upwelling suggest that it may be necessary to accurately specify local wind forcing as well as the Davidson Current and other external effects in order to forecast the SBC beyond a few days. Direct local vorticity generation by local wind curl may be secondary. Our SBC-demonstrated nesting technology has potential for detailed coastal nowcast/forecast systems.

## **IMPACT/IMPLICATIONS**

A major impact of this research is that we now have a working one minute (approximately two kilometer) horizontal resolution, 20-vertical level, SBC Model that shows extremely detailed flow features and local wind sensitivity. In conjunction with researchers at NPS, we also have a five minute resolution CC model with which we are implementing two-way nesting with our SBC model.

The SBC model runs about one model week per cpu-hour on a Silicon Graphics Indigo 2 workstation. On a newer Pentium Pro PC, the SBC model will run more than one month per cpu-day. The DieCAST model has thus been shown to have potential for high-resolution shipboard coastal forecast applications.

Ultimately, there will be triple nesting with a Pacific or global scale model, with data assimilation. Because the above results demonstrate realistic DieCAST model performance even without data assimilation, we expect that low-cost assimilation approaches such as simple nudging will keep the model on track with nature and thus yield an excellent nowcast/forecast capability.

## **TRANSITIONS**

In FY98 results from a high resolution SBC Model nested in our California Current model with data assimilation were delivered to ONR. The long-term objective is to deliver a prototype nowcast/forecast system for the SBC.

## **RELATED PROJECTS**

This project is being directly leveraged by ONR Research Grant N00014-97-1-0099 to CAST for Modeling with Data Assimilation in the North Atlantic (DAMEE).

This project is also being significantly leveraged by other ongoing research efforts, both nationally and internationally. For example, Texas A & M University and NRL Stennis are collaborating for general modeling of the Gulf of Mexico using DieCAST; the University of Auckland has adapted DieCAST and its new numerics as the New Zealand Regional Model; the New Zealand Electric Company uses DieCAST for the high resolution Doubtful Sound Model; Dalhousie University is working on adding data assimilation to the DieCAST version in the Gulf of St. Lawrence and Grand Banks Region; NRL Stennis is using DieCAST for high resolution modeling of Adriatic Sea nested within a 1/8 degree

Mediterranean Sea DieCAST model and for coupled Ice-Sea Modeling in the Arctic; Bedford Institute of Oceanography is investigating DieCAST performance in coastal zones and in the North Atlantic; NOAA National Marine Fisheries Service has used DieCAST in the Gulf of Mexico to study algal blooms; University of New South Wales in Australia is using DieCAST to run simulations for the East Australian Current and Tasman Sea; Australian Defense Forces Academy is running simulations in the Hawaiian Island area using DieCAST; NOAA Great Lakes Environmental Research Laboratory has configured DieCAST to run simulations in Lakes Erie and Michigan; Memorial University is using DieCAST for simulations in Newfoundland Bay; Florida State University has coupled DieCAST to an atmospheric model to investigate hurricane response; MIT and Canadian Meteorological Center have coupled DieCAST to the Canadian operational meteorological model; the Naval Postgraduate School is using DieCAST for modeling of the California Current, and Oregon State University is developing high resolution Southern Hemisphere and global scale versions of the DieCAST Ocean Model. Some other collaborations involve James Cook University, University of Trieste in Italy, UIB at Palma in Spain, Government of Bulgaria, Russian Federation, University of Otago and Leigh Laboratory in New Zealand, and CSIRO in Australia.

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